

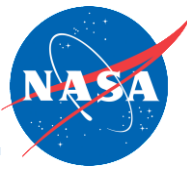


Fuel Effects on Black Carbon Mass and Number Emissions (All Results for Non-Contrail Conditions)

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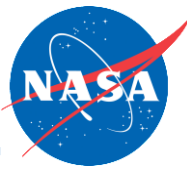
ACCESS-2 Science Team Meeting
Science Team Meeting
09 January 2015

Test Objectives



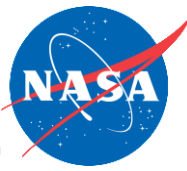
1. Examine the effects of Alt fuels on aircraft cruise-altitude gas and particle emission indices
2. Examine the impact of contrail processing on exhaust composition
3. Characterize the evolution (growth, changes in composition) of exhaust PM and how this is impacted by fuel composition
4. Investigate the role of soot concentrations/properties and fuel sulfur in regulating contrail formation and the microphysical properties of the ice particles.
5. Survey soot and gas-phase emissions in commercial aircraft exhaust plumes in air-traffic corridors to provide context for DC-8 measurements

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Engine Thrust Varied to Study Power-Dependent Emissions



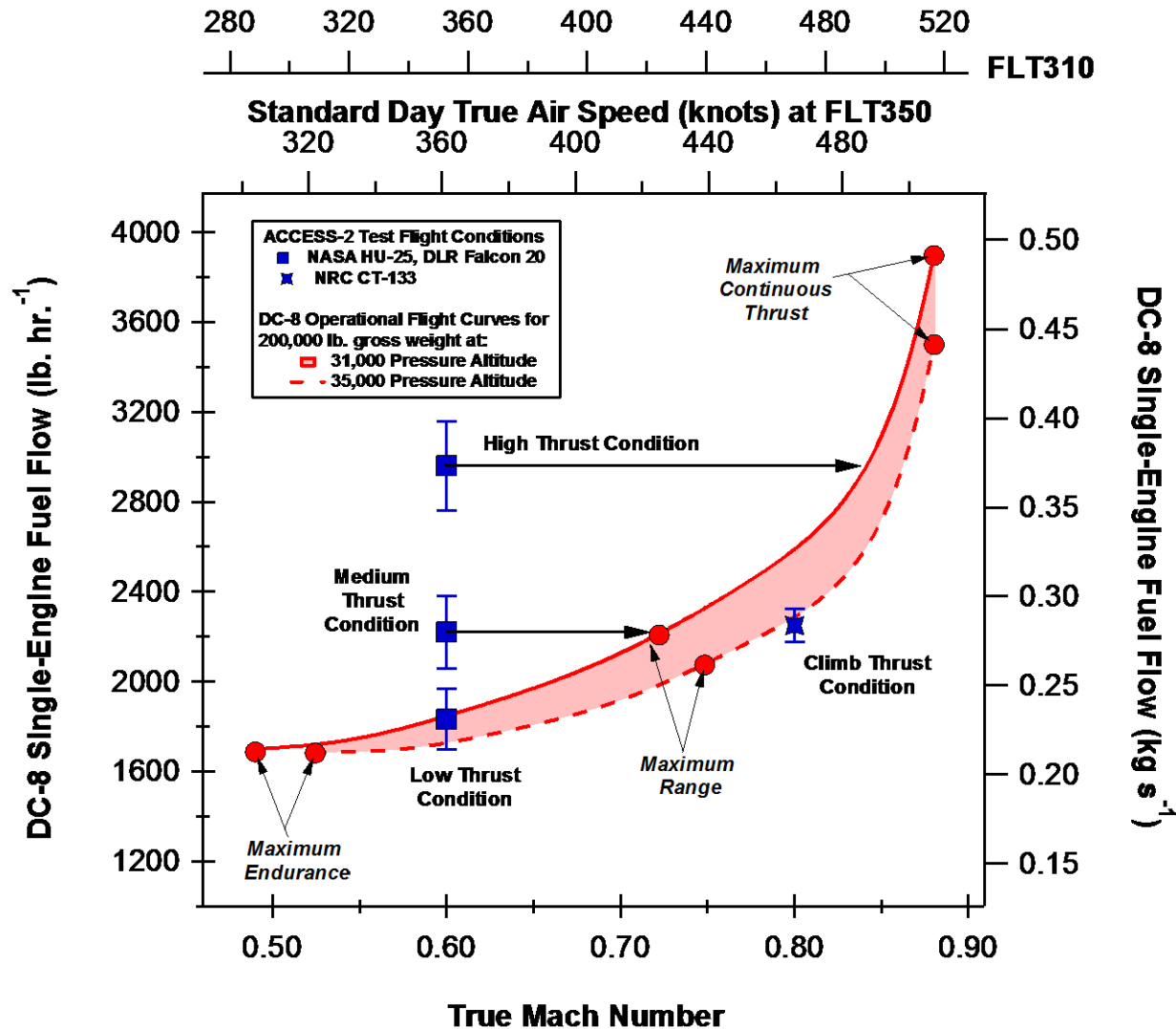
Inboard
Engines
Idled Back



Outboard
Engines
Idled Back

Varied Engine FF from ~ 1500 to 3000 lbs/hr, balancing Inboard/Outboard thrust to maintain constant 0.6 Mach

What are typical “cruise conditions” for the CFM56-2C1 Engines?



Red curve derived from cruise charts assuming 200,000 lb. gross wt. aircraft at FLT310 to FLT350.

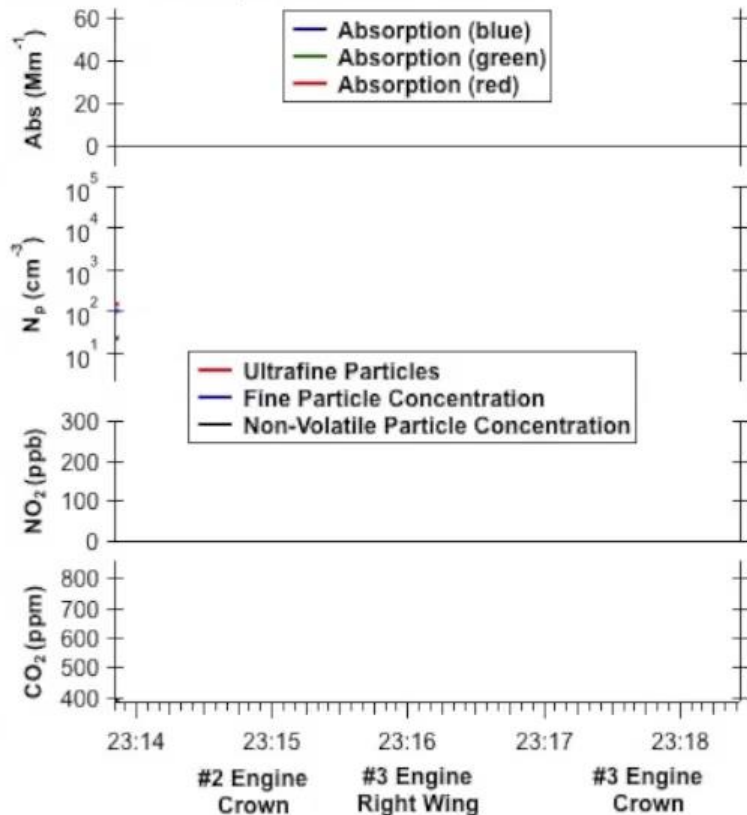
Time Series For Typical Set of Maneuvers



Right-Wing-Mounted Cloud Probe:

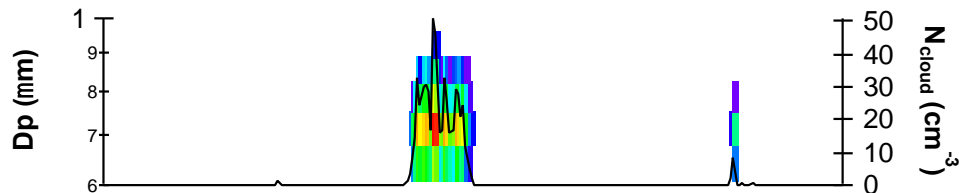


Crown-Mounted Sample Probe:

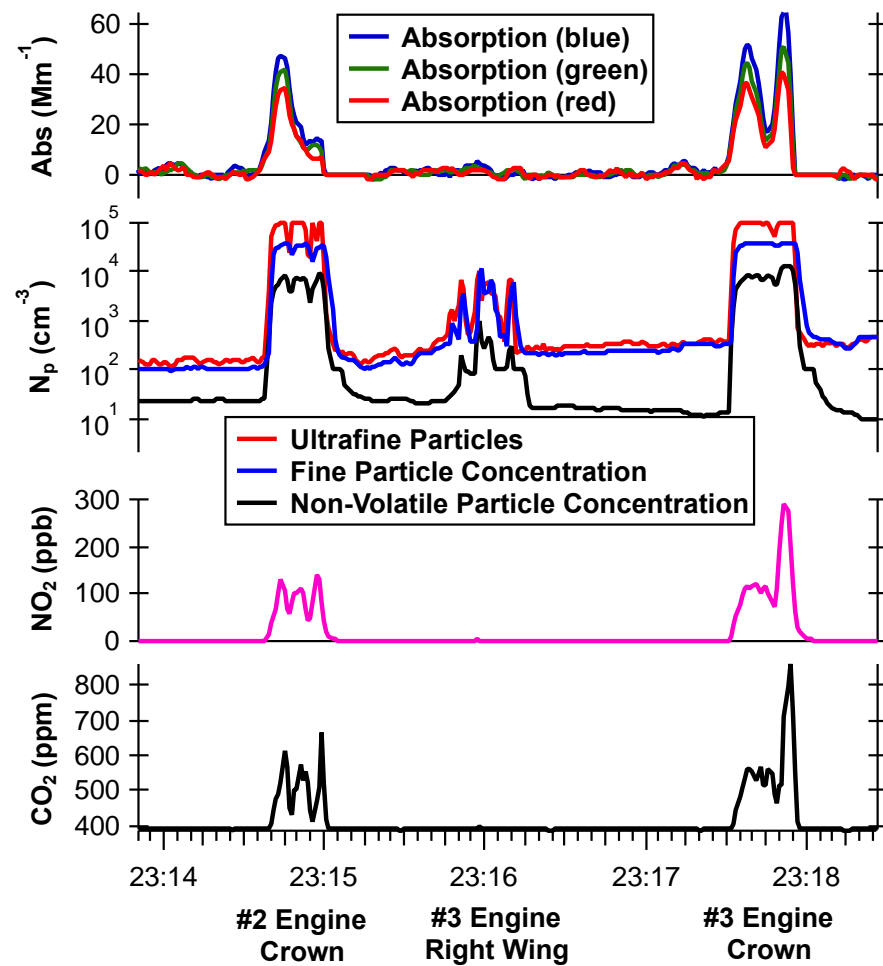


Typical Set of Manuevers

Right-Wing-Mounted Cloud Probe:



Crown-Mounted Sample Probe:



Background



#2 Engine Crown



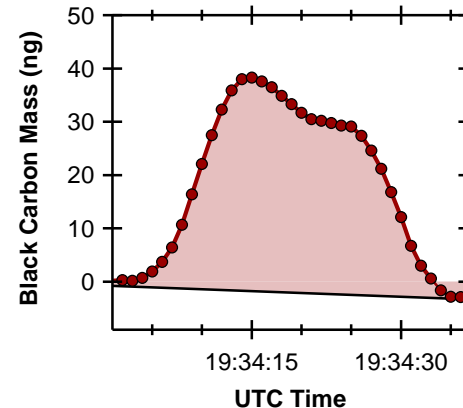
#3 Engine Right Wing



#3 Engine Crown

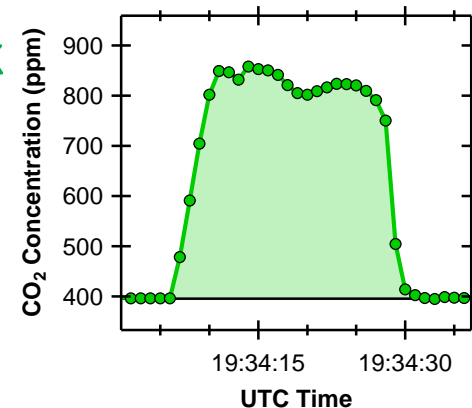
We use CO_2 to convert measured concentrations to emissions index in order to account for differences in plume penetrations:

Integrated Peak
Area of
Emission
Parameter, X



$$\text{Emissions Index, EI}_X = \frac{[X]}{[\text{CO}_2]} \left(\frac{RT}{P(M_C + \alpha M_H)} \right) \leftarrow \text{Constants}$$

Integrated Peak
Area of CO_2

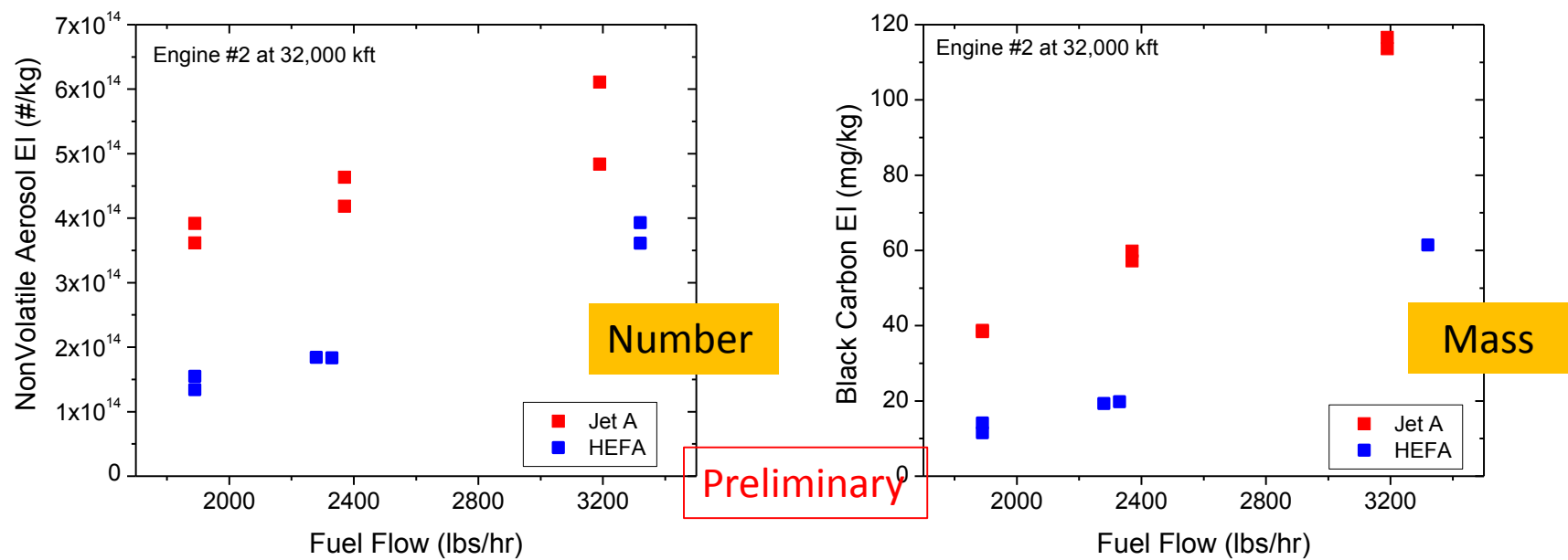


ACCESS-II

Cruise Data



HEFA Blend Reduces Black Carbon Number and Mass Emissions by 30 to 60% at Cruise



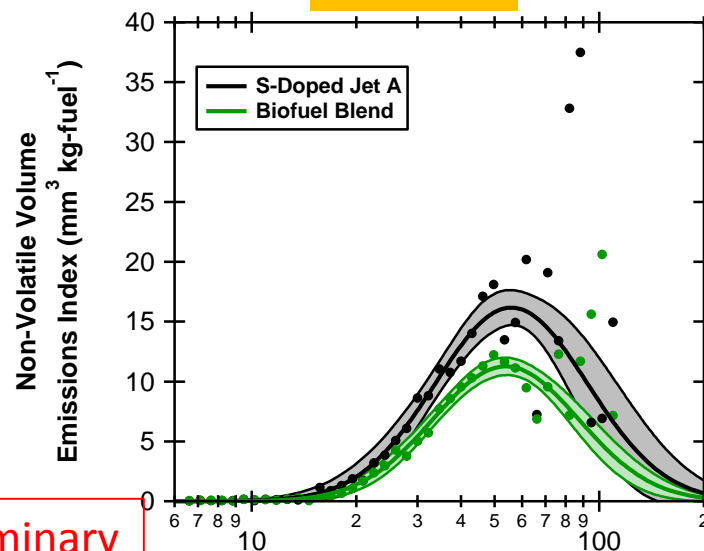
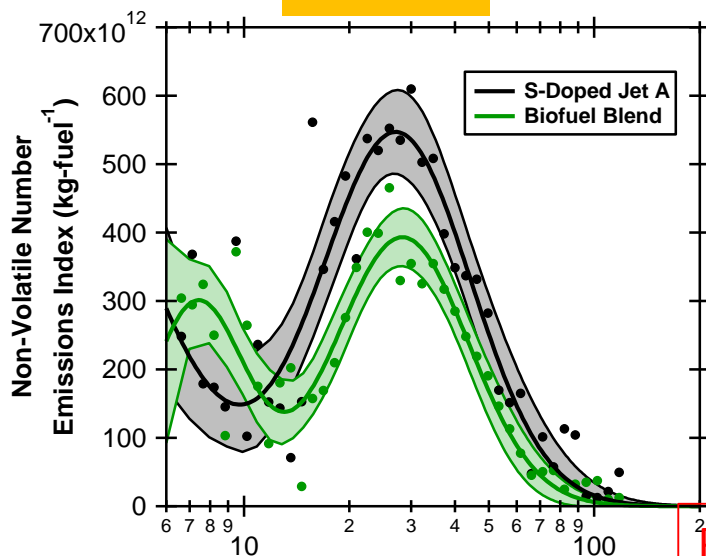
In-Flight Aerosol Size Distributions for Max. Efficiency at FLT320



Number

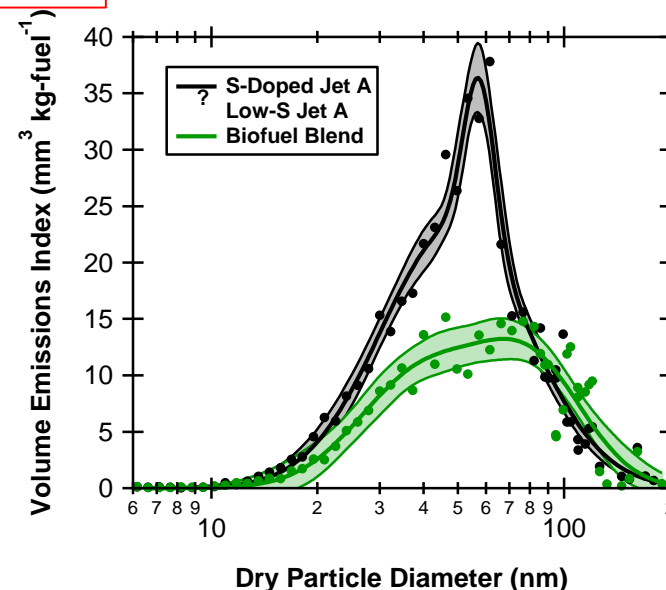
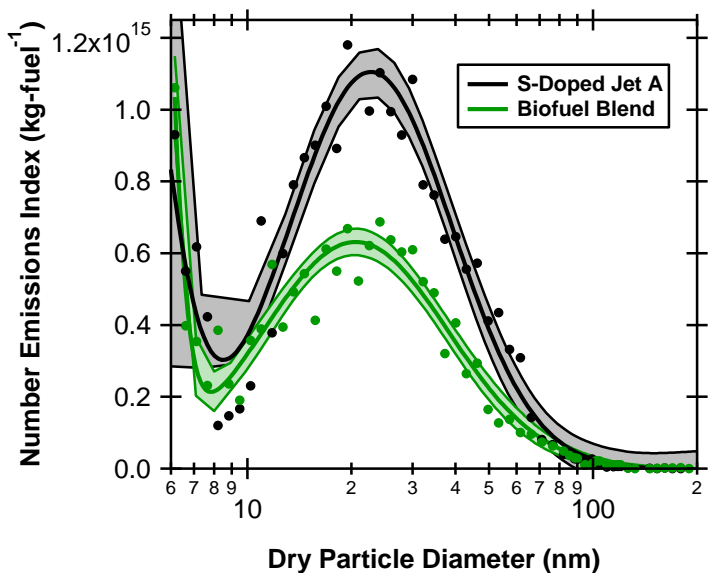
Volume

Non-Volatile



Preliminary

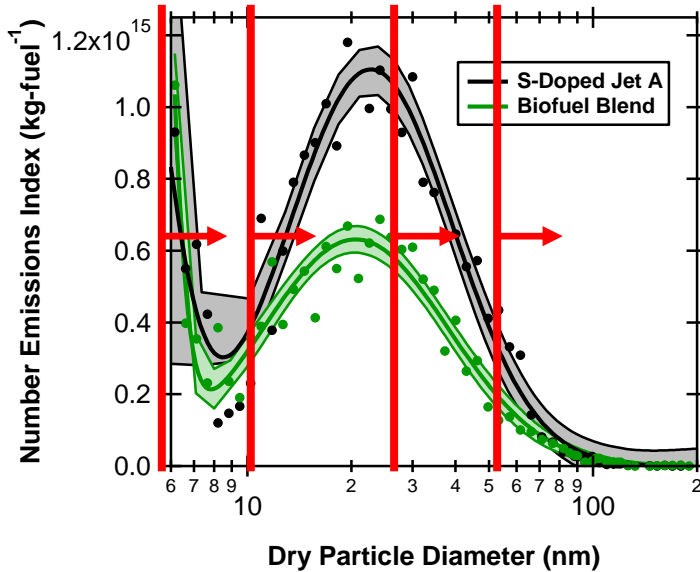
Total



In-Flight Aerosol Size Distributions Complement Other Measurements

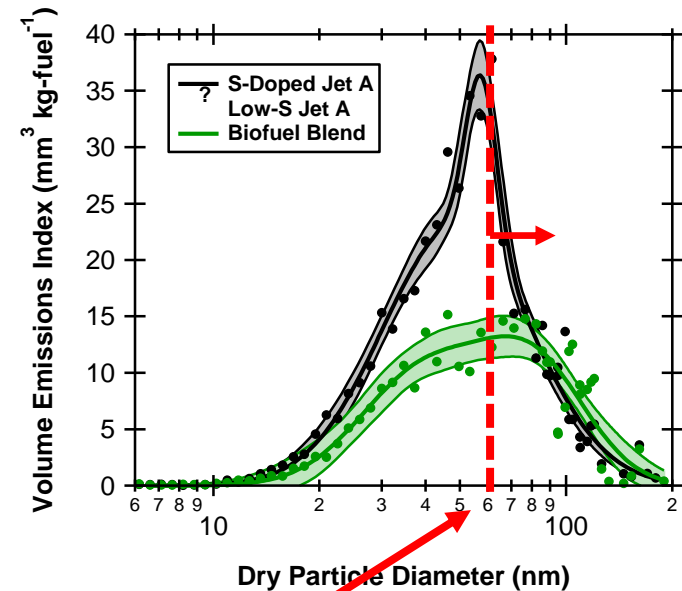
Discrete Number Concentration Measurements
on DLR Falcon 20 (Bernadett Weinzierl's talk)

Number



Total

Volume

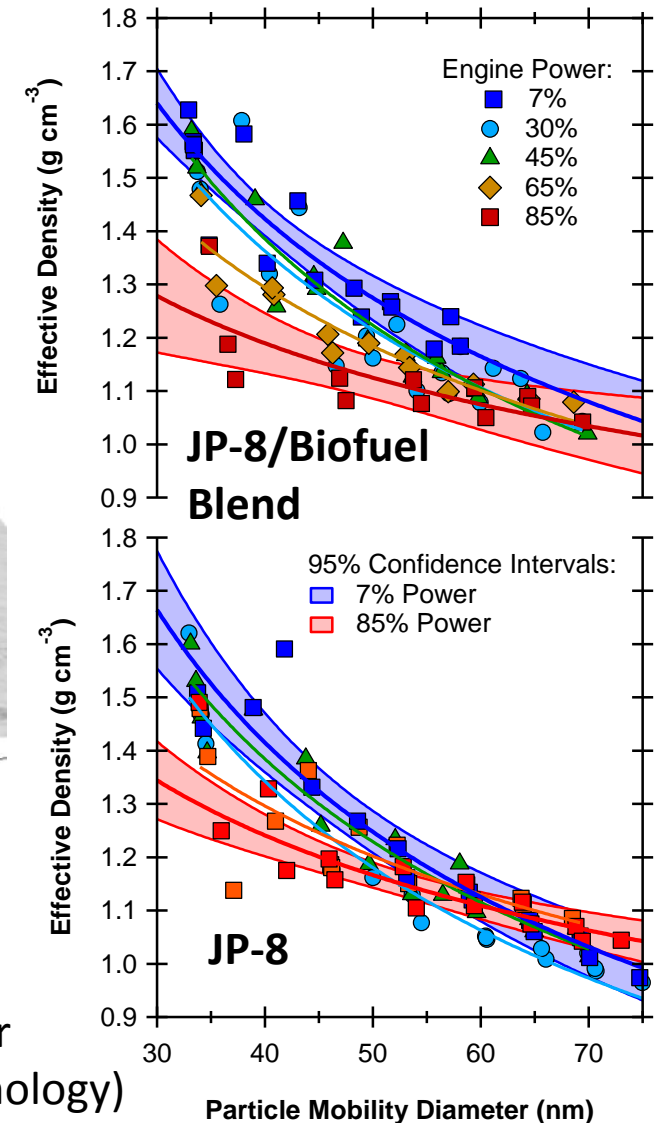
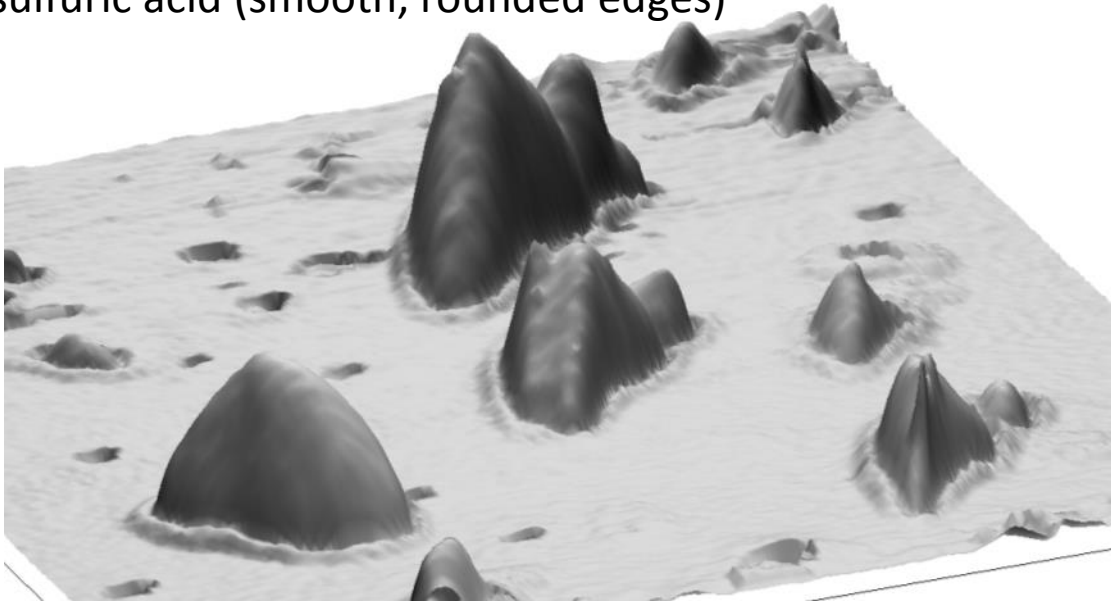


Ground testing conducted on 21 May 2014:
Top-down view of the ground test pad at NASA Armstrong with wind rose plot



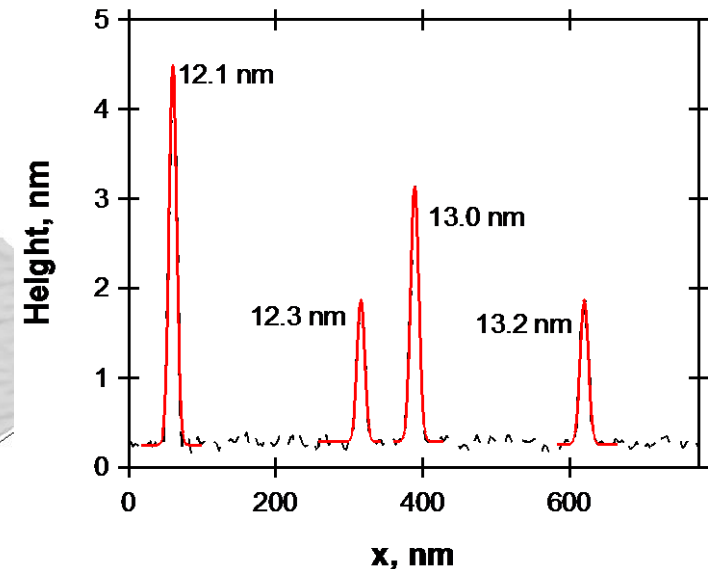
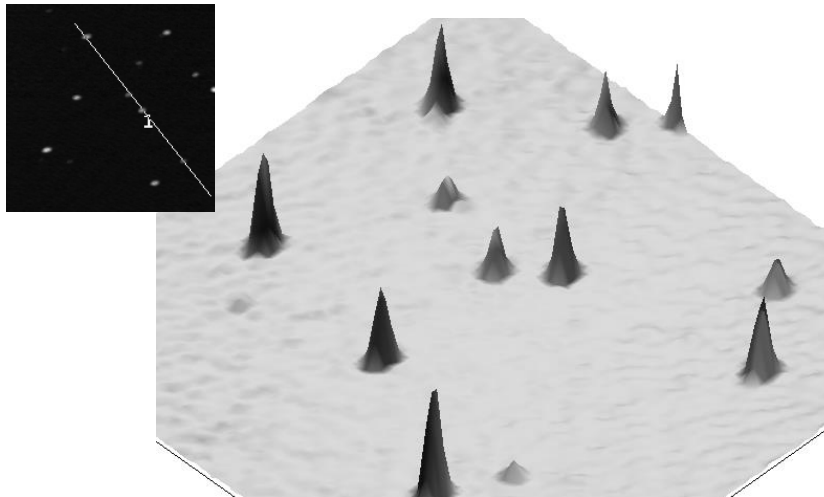
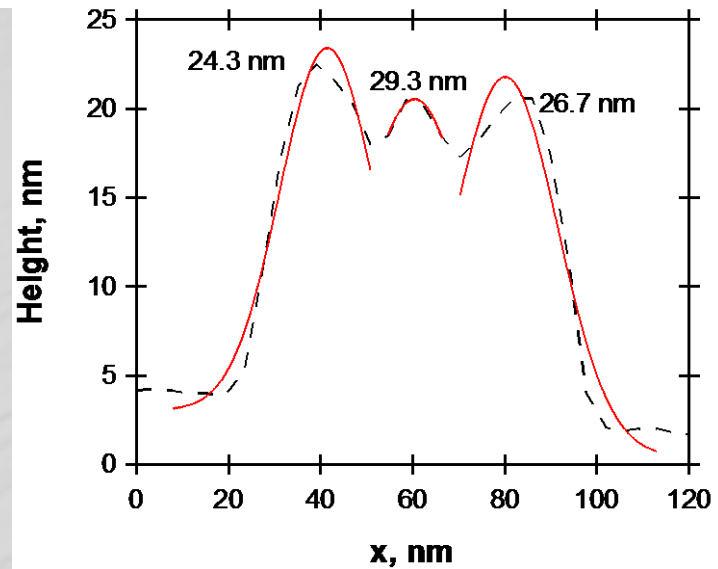
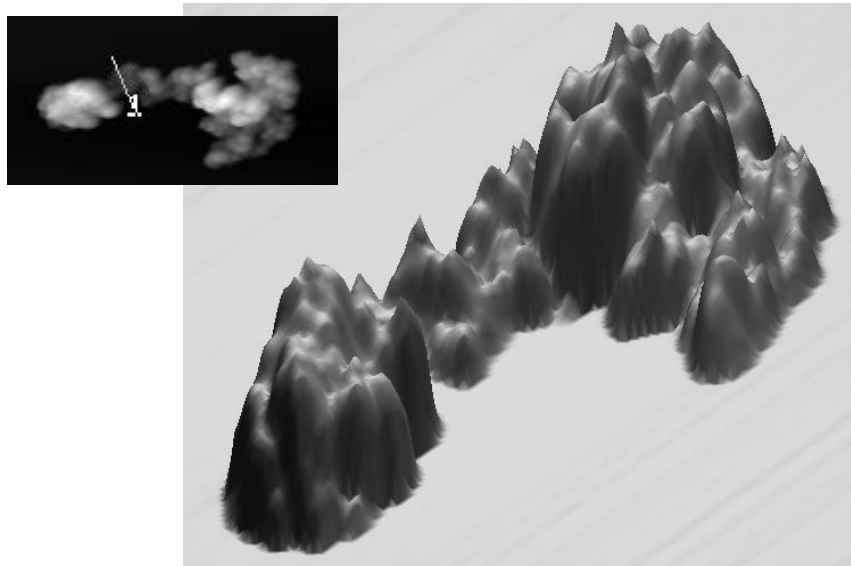
Additional instruments during the ground test can probe soot density and shape, but are not suitable for flight.

Atomic force microscopy image of soot particles, which appear to be coated with liquid organics or sulfuric acid (smooth, rounded edges)



Higher density soot observed at lower power settings (again likely due to liquid-like morphology)

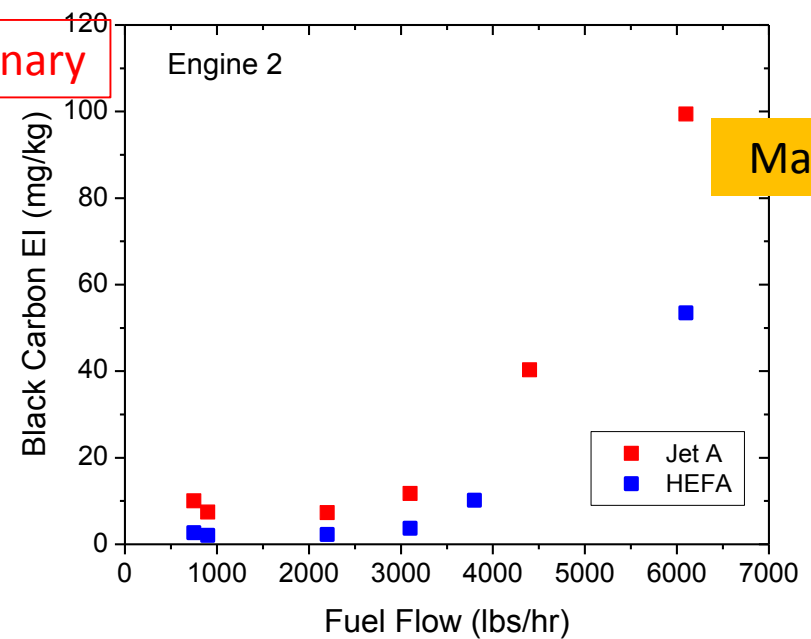
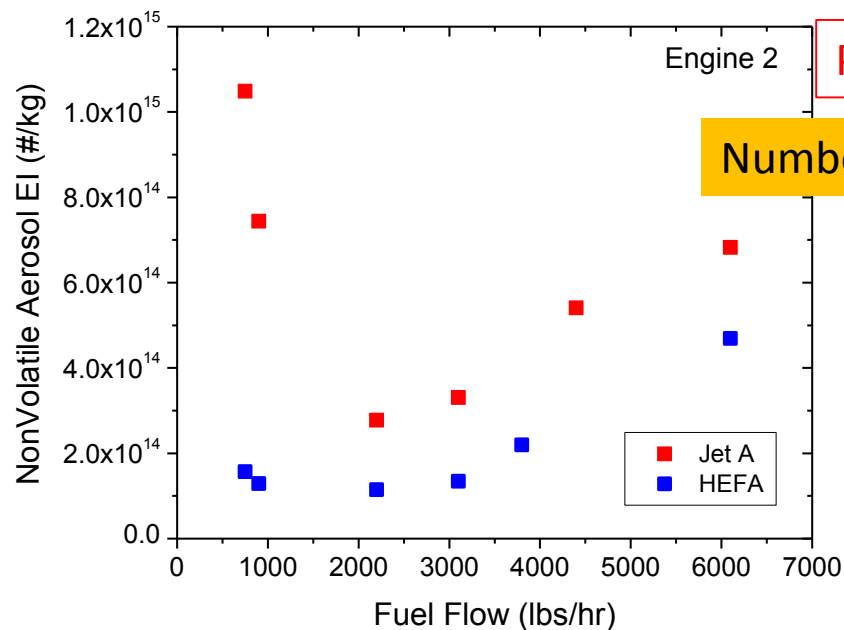
Atomic force microscopy (AFM) images of a large soot agglomerate at 45% engine power (top) and nucleation mode particles at 4% engine power (bottom).



Cruise EIs Consistent with Ground Test Measurements



HEFA Blend Reduces Black Carbon Number and Mass Emissions by 30 to 80% during Ground Ops



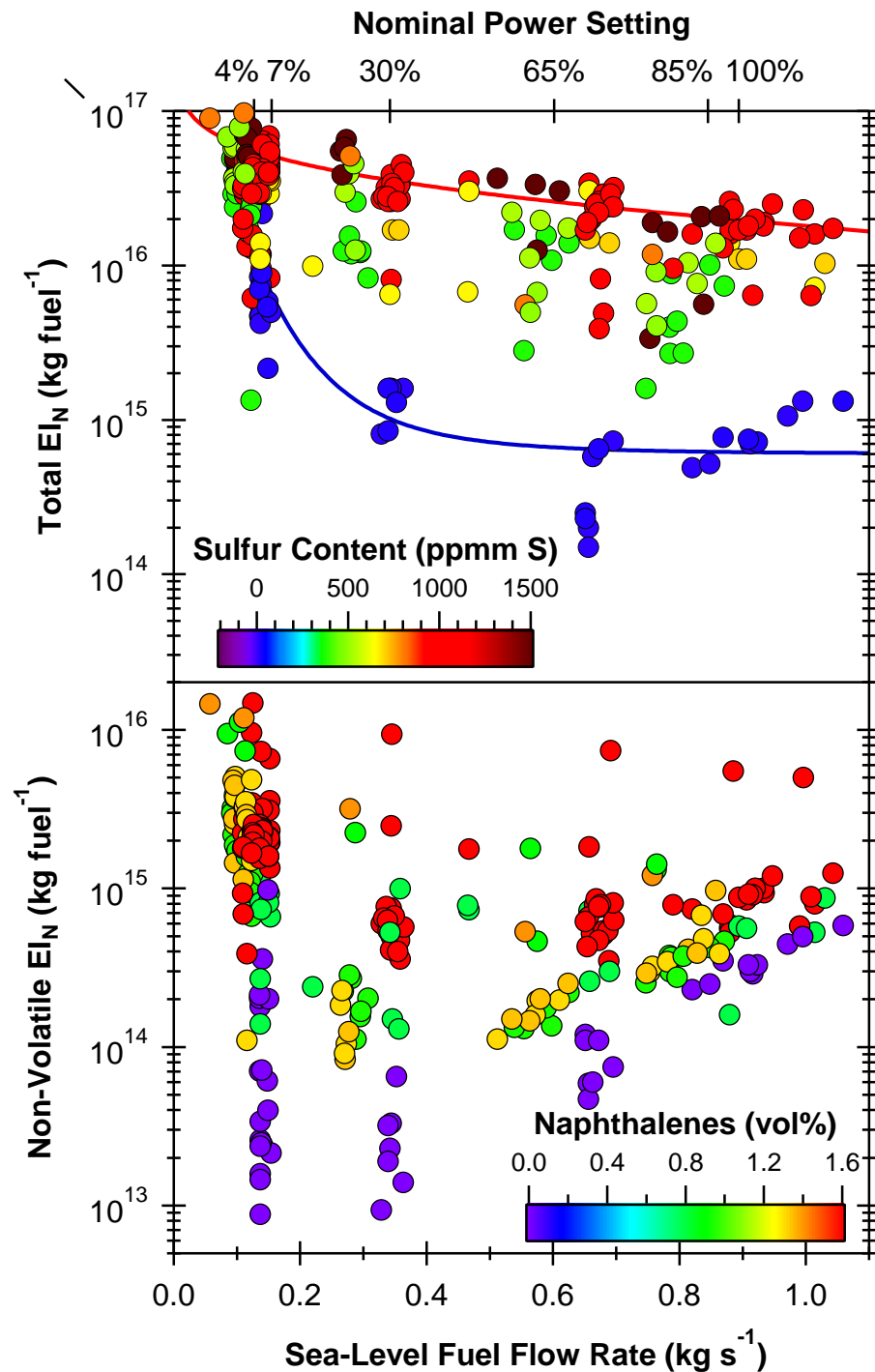
How do ACCESS-2 Results Compare to Past NASA Ground Tests?

Four Projects:

- 2004 APEX
- 2009 AAFEX-1
- 2011 AAFEX-2
- 2013 ACCESS-1

Fifteen different fuels, blends:

- JP-8 and Jet A
- Fischer Tropsch
- HEFA



How do ACCESS-2 Results Compare to Past NASA Ground Tests?

Medium-S Jet A (Solid Black):

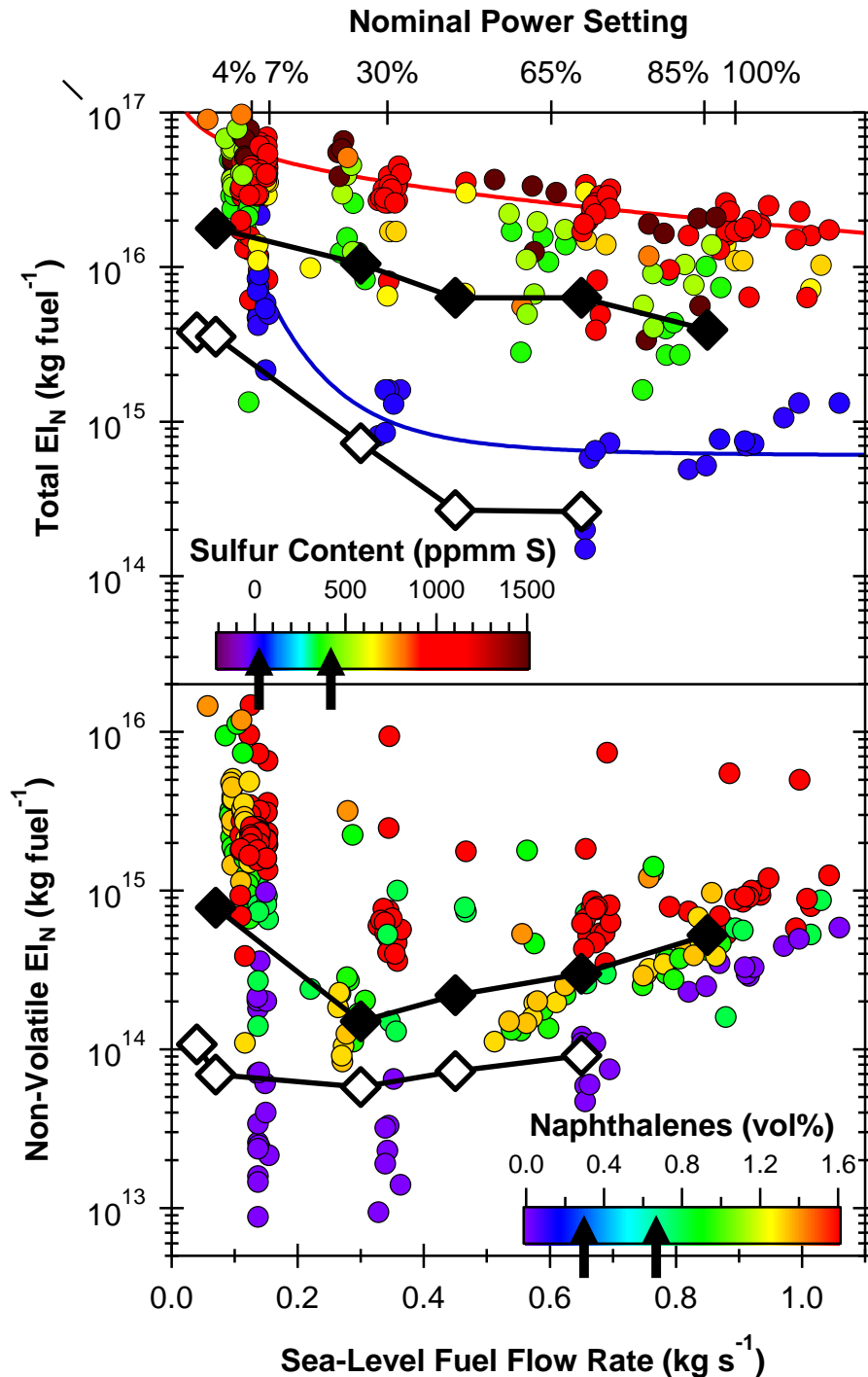
- Sulfur ~ 426 ppm
- Naphthalenes $\sim 0.7\%$ (v/v)

50:50 Low-S Jet A / HEFA

Blend (Open Black):

- Sulfur ~ 20 ppm
- Naphthalenes $\sim 0.4\%$ (v/v)

**Good agreement with past
NASA ground tests using a
variety of jet fuels!**

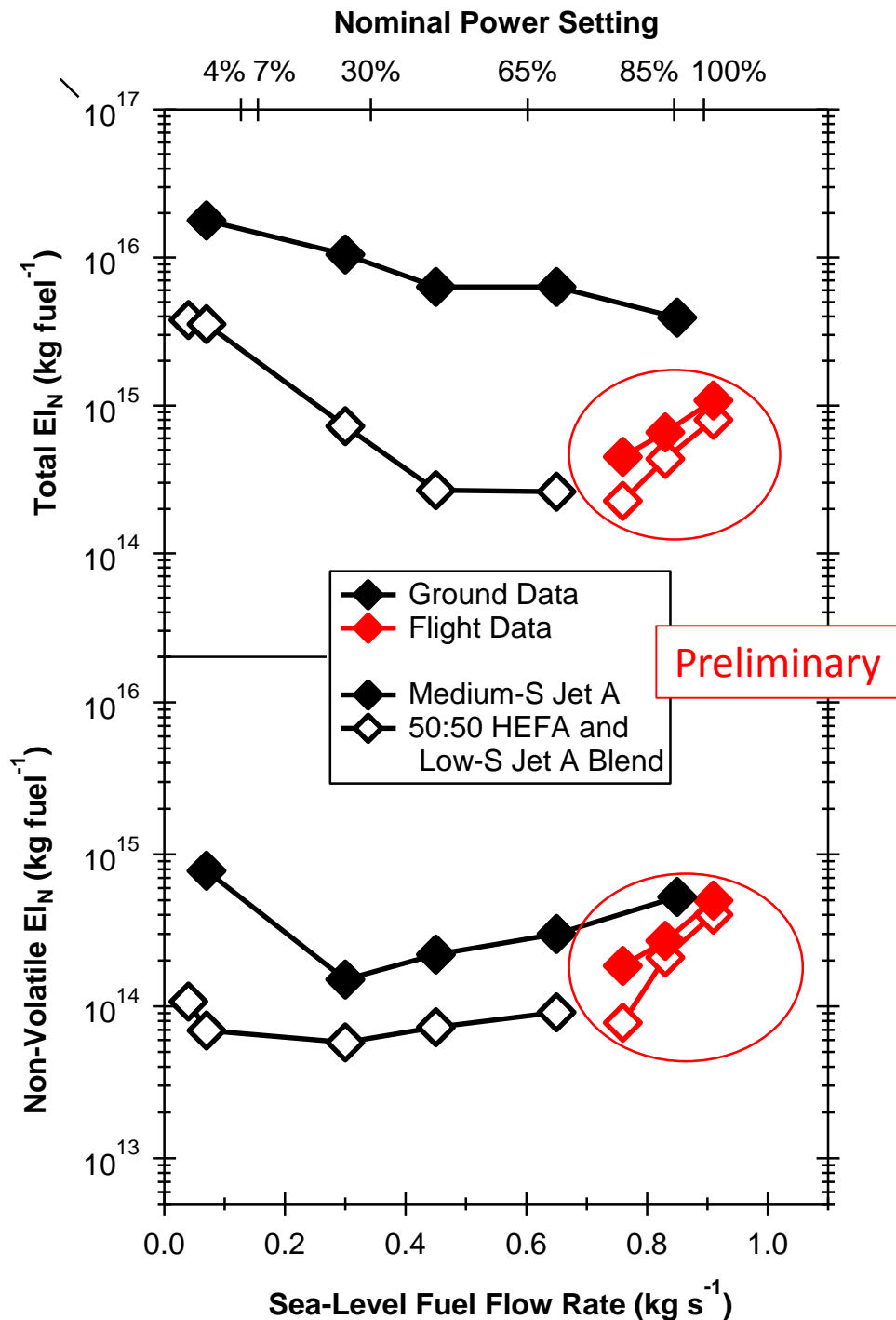


Putting it all together... ACCESS 2 Flight + Ground Measurements

Now superimposing the flight emissions indices w/o any corrections (shown in red)...

Same ballpark, but need to account for differences in combustor inlet conditions.

This work is ongoing in collaboration with partners at GE and Boeing.

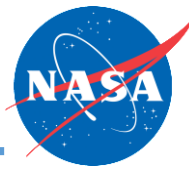


Alternative-Fuel Effects on Contrails and Cruise Emissions (ACCESS)



ACCESS Sponsored by NASA Fundamental Aeronautics, Fixed-Wing Program

ACCESS Fuel Properties (Recap)



ACCESS-2
(2014)

ACCESS-1
(2013)

Property	ACCESS-2 (2014)			ACCESS-1 (2013)	
	Medium Sulfur Jet A	Low Sulfur Jet A	HEFA: Low-S Jet A Blend	JP-8	HEFA: JP-8 Blend
Density (kg/m ³)	810	810	789	806	784
Sulfur (ppmM)	426	8.5	~9.1	800	500
Aromatics (vol%)	20.8	20.8	12.9	16	8
Heat of Combustion (MJ/kg)	43.2	43.2	43.5	43.3	43.0
Hydrogen, (wt%)	13.8	13.7	14.5	13.9	14.4
Napthalenes (vol%)	0.7	0.7	0.4	1.5	0.9
Olefins (%vol)	0.7	0.7	0.7	1.1	1.1